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Influence of $CaCl_2.2H_2O$ content on the productive process of composites from cotton gin waste

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Abstract

Previous studies have shown the feasibility of production of masonry blocks and panels from agglomeration of cotton gin waste and calcium binders. Cotton gin waste is a serious problem for ginning plants, because in Argentina approximately 300,000 t of lignocellulosic wastes are produced annually without any final disposal destination. The accumulation of these residues is associated with pests and fire hazards. Since these composites are produced with simple equipment and a minimum energy requirement, their cost depends mainly on the binder (Portland cement) used and the process efficiency, since with a high productivity model, labor and equipment depreciation costs are significantly reduced. This paper analyzes the influence of $CaCl_2.2H_2O$ (added as an accelerator for cement paste strength) on the minimum molding time required for composites manufacturing. A central composite experimental design was developed in order to study the interrelated variables. The influence of $CaCl_2.2H_2O$ content on physical-mechanical cement paste properties and their relationship with composites stability are also evaluated. The results of this work show that $CaCl_2.2H_2O$ content has significant influence on the efficiency of composites manufacturing as it reduces the molding time required.

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Keywords: *Cotton gin waste; composites; stripping;* $CaCl_2.2H_2O$.

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1. Introduction

Cotton production is an important activity in the provinces of Santa Fe, Chaco, Formosa, Santiago del Estero, and Corrientes, with a high geographical concentration. In the last seasons, 1,000,000 t raw cotton were obtained, which produced 300,000 t (Agriculture Office (2014) and Montenegro et al. (2013)) (approx. 1.195.000 m^3) of cotton gin waste (30%) with no disposal destination. As mechanical harvest continues developing, as it improves crops profitability, more cotton gin waste is being produced. In many cases, this waste is burned, and as many ginning plants are within urban areas, it causes serious pollution problems, respiratory diseases and other ailments (PNUMA (2005) and El Liberal (2009)).

The development of innovative building elements from cotton gin waste contributes to solve important problems in this agribusiness area in Argentina, such as environmental pollution, housing shortage, poor thermal insulation (Diario Uno (2006), Census 2001 (2005) and Census 2010 (2012)), and lack of employment for unskilled labour (Piccioni et al. (2013) and Piccioni et al. (2013)).

Tests conducted (Piccioni et al. (2013) and Piccioni et al. (2013)) showed that building elements with suitable mechanical properties, low specific weight, and low thermal conductivity, such as blocks and boards, can be produced from agglomeration of cotton gin waste and cement. The use of these blocks can help to improve hygrothermal behavior for vertical enclosure structures (external walls), as they reduce thermal transmittance up to a 74 %, as compared to common masonry ceramic bricks. Roofing elements from cotton gin waste can also help to improve the behavior of roof enclosures, without using expensive materials, by reducing 80 % thermal transmittance, as compared to structures without thermal insulation (Piccioni et al., 2013).

The manufacture of these composites requires simple equipment for the mixing, binding, and molding process, with molding pressure of up to 0.4 MPa. According to the productive process designed and the cost estimates, the percentage composition of the value of a block is: 44 % materials, 0.12 % energy, 2.3 % equipment depreciation, 36 % labor, and 17.6 % benefit. These figures show that the cost of the building element depends mainly on the amount of the binder used (cement) and on the efficiency of the process. A higher productivity level implies lower expenses on labor and lower equipment depreciation.

The improvement on the efficiency for composite manufacture depends mainly on the minimum molding time required, as the cement paste that binds the particles of cotton gin waste needs to reach a minimum strength level. As it is shown in Fig. 1, it is considered that the tensile strength of the cement paste must equal or exceed the conformation pressure of the composite to allow the stripping without material failures.

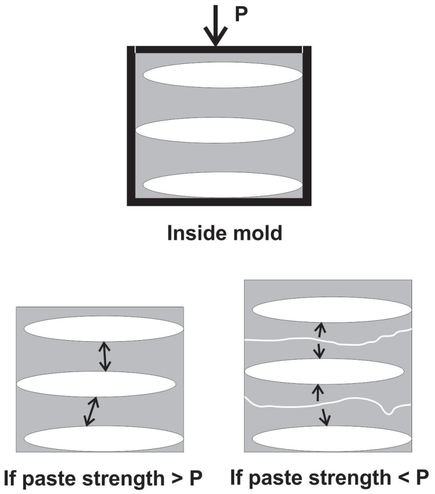

Fig. 1. Diagram of behavior of composites.

An option to improve strength gain rate, is to add accelerating admixtures to the cement paste. $CaCl_2$ is one of the most common additives. It accelerates the development of initial strength because it acts as a catalyst in the silicate phase hydration of clinker (Neville, 1998). Some authors claim that 1-2 % of $CaCl_2$ is, in general, enough to significantly improve strength at early ages (Neville (1998), Mehta et al. (1993) and Soroka (1979)). $CaCl_2.2H_2O$ containing 75 - 77 % of $CaCl_2$ is commercially available, at an affordable price, and it does not require special protection or safety measures for handling.

This work analyzes the effects of varying dosages of $CaCl_2.2H_2O$ on the strength of cement paste used for the manufacture of composites, on the stability of the composites obtained, and on their compressive strength.

2. Materials and Methodology

The materials used for this work were raw cotton gin waste (without any treatment), PC40 Portland cement (PCC, IRAM 50000), and $CaCl_2.2H_2O$ flakes, industrial quality, with a 77 % $CaCl_2$ content.

A central composite experimental design (Montgomery et al., 1996) was developed to determine the dosages of $CaCl_2.2H_2O$ to be added and the molding time, and to assess the composites as an interrelated variables dataset. This design allowed evaluating the mechanical strength of the cement paste and the stability of the composites through the analysis of the response surface for the domain determined (Fig. 2).

The equation of the model is given by equation 1 (Spiegel et al., 1988):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_{12} + \beta_4 X_{22} + \beta_5 X_1 X_2 ..... \tag{1}$$

where Y is the property studied (paste flexural strength or composite expansion), X_1 and X_2 are the experimental variables (X_1 is the percentage of $CaCl_2.2H_2O$, varying from 1 to 4.5 % by cement mass, and X_2 is molding time, varying from 4 to 24 h), and β_0-β_5 are the coefficients estimated using the method of least squares.

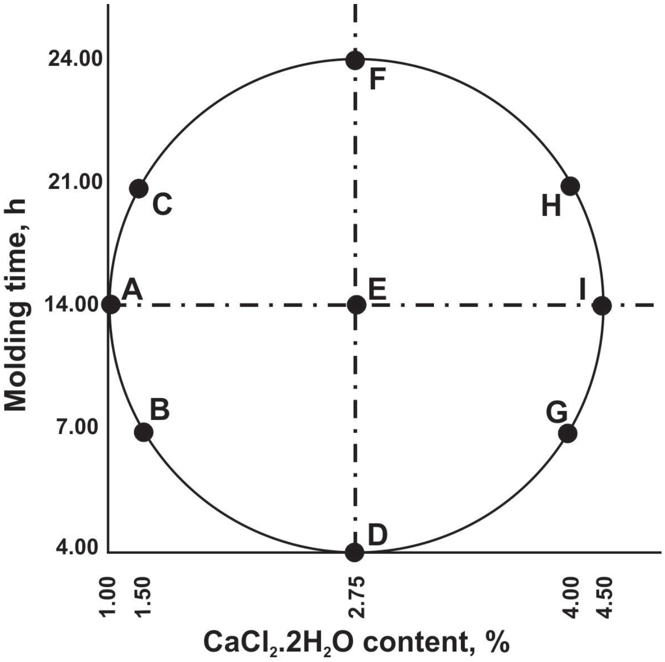

Fig. 2. Experimental design.

In order to evaluate the stability of the composites, prismatic blocks were produced with a water/waste ratio of 1.3 by mass, a water/cement ratio of 0.77 by mass, and a molding pressure of 0.40 MPa (Piccioni et al., 2013). Height was measured in the center of the 4 lateral faces immediately after stripping and after 24 h of stripping. Based on these measurements, the expansion of the elements was calculated as a percentage of the height recorded at stripping time.

The strength gain of the cement paste was measured on pastes with a water/cement ratio of 0.77 by mass. Cement paste test probes of 25 x 25 x 140 mm were molded and tested for flexural strength with a center load, immediately after stripping. For the flexure test, a span of 100 ± 1 mm was used. The results were obtained as the average of 4 tests. Although the point of interest for the assessment of this phenomenon was the tensile strength, this value is very difficult to obtain due to the secondary stresses produced during the tests. Thus, flexure test was conducted instead.

For both blocks and pastes, the dosage of $CaCl_2.2H_2O$ used ranged from 1 to 4.5 % by cement mass, and the molding time ranged from 4 to 24 h, according to the experimental design.

Finally, the blocks corresponding to the experimental points identified as A, E, and I, were tested for compressive strength. As it is a non-conventional material, with a stiffness lower than that of traditional concrete or ceramic masonry blocks, the tests were conducted considering as compressive failure load the load causing a 10 % deformation of the original height of the test block.

3. Results and discussion

Fig. 3 shows the response surface obtained for the block expansion as a function of $CaCl_2.2H_2O$ content (abscissas) and of molding time (ordinates), measured after 24 h of stripping.

The values of expansion ranged from 0.85 % (experimental point F) and 16.90 % (experimental point D). The correlation coefficient obtained for the expansion model was 0.95. It can be observed that as $CaCl_2.2H_2O$ content and molding time increase, expansion tends to decrease. The isoresponse surface obtained showed a minimal curve, which is close to an incline plane whose slope depends mainly on the $CaCl_2.2H_2O$ content added. This behavior suggests that the higher the $CaCl_2.2H_2O$ content and the longer the molding time, the higher the strength levels achieved for the binder, which permits a higher stability for the composites.

The results in the Fig. 4 confirm this hypothesis, because as $CaCl_2.2H_2O$ content and molding time (equivalent to test age) increase, the flexural strength of the cement paste tends to increase. In this case, it can also be observed that the isoresponse surface shows a slope that responds, mainly, to the $CaCl_2.2H_2O$ content added. The flexure strength determined in these tests ranged from 0.1 MPa (experimental point B) to 1.05 MPa, (experimental point F) with a correlation coefficient of 0.98 for the model of flexural strength of pastes.

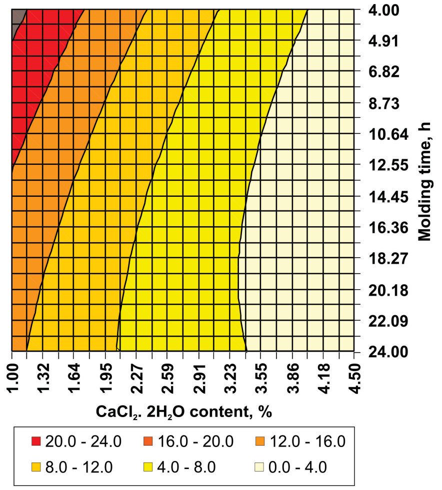

Fig. 3. Response surface for expansion of blocks (%).

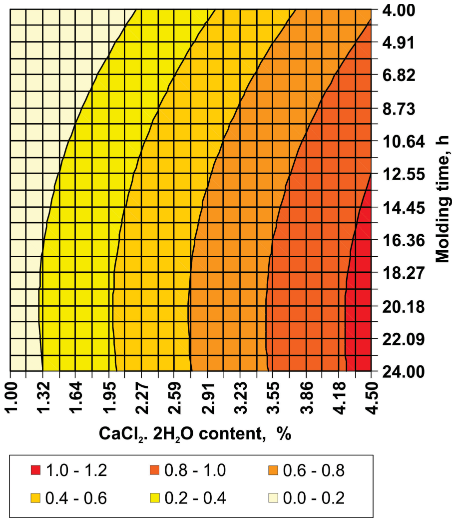

Fig. 4. Response surface for the flexural strength of cement pastes (MPa).

Considering these data and the coefficients estimated by the method of least squares for the strength of the pastes, it is possible to obtain the minimum $CaCl_2.2H_2O$ required for safe stripping after a maximum of 8 h of molding time. In the formula corresponding to the isoresponse surface, X_2 value should be replaced by 8 h and the inequation should equal the flexural strength value of 0.8 MPa corresponding to the double of the molding pressure used. It is concluded that a minimum content of 4.14 % $CaCl_2.2H_2O$ is required to obtain the necessary flexure strength. It can also be observed that a higher addition of $CaCl_2.2H_2O$ can lead to an increase in strength in the composites produced, a strength even higher than the one obtained for longer molding times (Fig. 4).

Finally, in Fig. 5 the effect of the expansion of the composites on the compressive strength is evaluated. It can be observed that the increase in expansion produced by poor strength of cement paste at stripping has a significant effect on the compressive strength of the blocks. As a consequence of the instability of the composites, there is a decrease in strength in the order of 0.15 MPa per 1 % of increase in expansion.

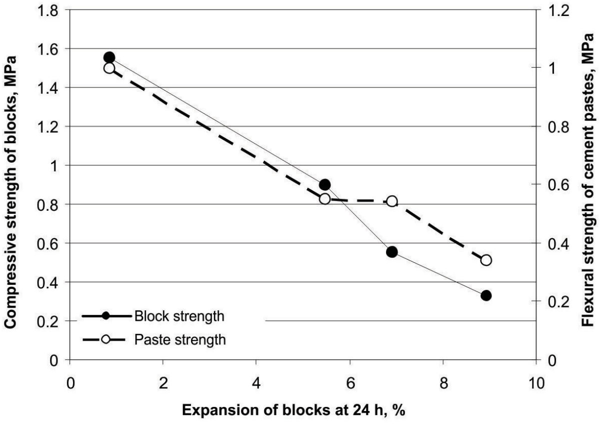

Fig. 5. Variation of block strength as a consequence of block expansion.

4. Conclusion

From the results obtained in this work, it can be concluded that it is possible to reduce the molding time required for the binding of the composites from cotton gin waste by adding varying contents of $CaCl_2.2H_2O$.

The studies carried out for this work showed that the instability of these composites with short molding times is caused by a lack of strength of the cement paste used as a binder, which cannot bear the tensile stress produced in the particles of the residue when released from the mold.

It can be estimated that with an addition in the order of 4 % it is possible to reduce molding time from 24 to 8 h and also to improve the mechanical behavior of the composites, without changing the manufacturing process and without increasing material cost (as it is an accelerating of industrial quality) and with an important decrease in the labor cost and equipment depreciation.

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